Dynamics of profiles and storage of carbon dioxide in broad-leaved/Korean forest in Changbai Mountain

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Abstract: CO_2 concentrations at different heights in a broadleaved/Korean forest (with a mean height of 26 m) were measured with infrared gas analyzer IRGA (model 2250D, LI-COR Inc. and LI-COR, 820) from Aug. to Oct. of 1999, Apr. to Jul. of 2000, and from Aug. 2002 to Sept. 2003. Based on the collected dada, the diurnal and seasonal dynamics of profiles and storage of carbon dioxide in the forest were analyzed. The diurnal CO_2 profiles showed that the vertical distribution of CO_2 concentration were different for daytime and nighttime, and the CO_2 concentration was highest close to forest floor, no matter at daytime and nighttime. The seasonal profiles of CO_2 showed that stratification in the canopy was evident during growth season. CO_2 concentrations at different heights (60 m to 2.5 m) had a little change in March, with a difference of 10 $\mu mol \cdot mol^{-1}$, but had a significant change in July, with a difference of 60 $\mu mol \cdot mol^{-1}$. In July, there also existed a greater gradient of CO_2 concentrations at canopy (22, 26 and 32 m), with a difference of 8 $\mu mol \cdot mol^{-1}$. The calculated total storage ($\Delta C/\Delta t$) of CO_2 in the air column with height of 40 m beneath eddy covariance instrument was negative, and made a little contribution to NEE.

Keywords: CO_2 concentration, CO_2 profile, CO_2 storage, Broadleaved/Korean pine forest, Vertical distribution, Concentration gradient

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Introduction

The eddy covariance technique has been widely used to estimate the net ecosystem exchange (NEE = $Fc + \Delta C/\Delta t$) between the atmosphere and vegetation or soil, where $\Delta C/\Delta t$ that can be expressed by the CO_2 profiles is the change of the CO_2 storage in the air column beneath the eddy flux sensors (Yang *et al.* 1999). The CO_2 profile is the distribution of carbon dioxide along vertical direction in forest, and it is govern by three main factors: turbulent mixing with the atmosphere above the canopy, photosynthesis, and respiration (Brooks *et al.* 1997). The photosynthesis and respiration from vegetation and soil act as source or sink within forest. The respiration of vegetation and soil acts as source, photosynthesis provides a net sink during daylight hours, and the atmosphere above the canopy acts as source in daytime and as sink in nighttime (Norisada *et al.* 1998). Studies on CO_2 profiles in forest have shown CO_2 had a vertical stratification within canopy during midsummer, and had the highest concentrations near the soil surface (Sparling and Alt 1966; Brooks *et al.* 1997; Garret *et al.* 1978; Wofsy *et al.* 1988, DeSelm 1952, Bergen 1971). However, these studies mostly focused on profiles of CO_2 within coniferous forests and hardwood forests, there was few reports on broadleaved-coniferous mixed forest, and no report on broadleaved/Korean pine (*Pinus koriaensis*) forest in Changbai Mountain.

The objective of this study is to determine the seasonal and diurnal variations and storage dynamic in CO_2 concentrations occurring within the broadleaved/Korean pine forest, so as to understand the contributions of the storage of CO_2 to the carbon flux in broadleaved/Korean pine forest in Changbai Mountain.

Experimental methods

Site description

The forest (42°24'09'N, 128°05'45'E, elevation 738 m) for measurement is located near Erdaobaihe Town, Jilin Province in Northeastern China. In this area, broad-leaved/Korean pine forest is the major forest type with multiplayer and different ages. The forest could be vertically divided into five layers: The first layer is overstory, which is made up of *Pinus koriaensis* and *Quercus mongolia*, the second layer is composed of *Tilia amurensis* and *Fraxinus mandshurica*, the third layer is composed of *Populus davidiana* and *Ulmus propinqua*, the fourth layer is understory, which is made up of *Corylus mandshurica* and *Eleutherococcus senticosus*, and the fifth layer is herbage-layer including the dominant species of *Brachybotrys paridiformis*, *Phryma leptostachya*, *Lmpatiens noli-tangere*, *Athyrium multidentatum* and *Carex callitrichos*. Old trees of the stand were about 200-years old. The forest is with a mean canopy height of 26 m and a density of 560 stems

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per hectare. Forest soils are Mountain dark brown forest soils (pH5.3-5.6). The annual mean air temperature of this area is 3.6℃ and annual mean precipitation is 713 mm.

Profile and storage of CO_2

From August to October of 1999, and from April to July of 2000, the CO_2 concentrations at different heights (0.4, 3.0, 8.0, 16.0, 22.0, 26.0, 28.0, 32.0, 40.0, 50.0 and 62.5 m) were measured with an infrared gas analyzer (IRGA) (model 2250D, LI-COR Inc.). This infrared gas analyzer is equipped with a twelve-input manifold, which are connected to the twelve Teflon tubes at different heights on the steel tower. Air was drawn from the Teflon tubes and pumped into IRGA by a pump. The CO_2 concentration was recorded by a personal computer. Air sampling frequency was designed at an interval of 30 s for each height and six minutes were needed to complete the measure of all the designed heights. From Aug. 2002 to Sept. 2003, the CO_2 concentrations were measured by IRGA (LI-COR, 820) instruments, and the inlets were separately mounted at seven heights (2.5, 8.0, 22.0, 26.0, 32.0, 50.0 and 60.0 m) on the tower. A three-dimensions sonic anemometer (Model CSAT-3, Campbell Scientific) was mounted at height of 40.0 m. A data collector (LI-COR, CR5000) was used to collect data of carbon dioxide concentrations from the infrared gas analyzers and transmit the data to the computer.

The profiles of CO_2 that were gained by the analyzers ADC-2250D or LI-COR-820 were used to estimate the storage of carbon dioxide in forest. Only those concentrations at various heights between the eddy covariance instruments and ground are required for estimating the CO_2 storage by profiles of CO_2. The storage of carbon dioxide is defined as $\Delta C/\Delta t$, where ΔC is the change of CO_2 concentrations in the air column beneath the eddy covariance sensors (40 m). The dimension of storage is as the same as flux ($mg \cdot s^{-1} \cdot m^{-2}$). The statistical interval was 30 min in data processing, The estimating methods of CO_2 storage see the literature reported by Yang *et al.* (1999).

Photosynthesis and leaf area index (LAI)

Temperatures of air and soil (5cm depth) were measured at the same time as measuring the data of profiles. Monthly average temperature was used for estimating the CO_2 storage. The data of temperatures of air and soil in 1999 and 2000 used in this study were provided by the Research Station of Forest Ecological System of Changbai Mountain, CAS, while the air temperature and soil temperature for the year of 2002-2003 were measured by sensor (Model HMP45C, Vaisala Inc.) and probes (105T, Campbell Scientific), respectively.

The photosynthesis and LAI for different layers (upper, mid-, and down canopy) were measured with LI 6400 and Plant Canopy Analyzer (Model LAI-2000, LI-COR) respectively. The state of intercepting and capturing light by canopy was evaluated by measuring photosynthetic active radiation at 32.0 m with a quantum sensor (LI190SB, Licor Inc.) and at 2 m with five bars (per bar with ten quantum sensors, LQS70-10, Apogee Inc.).

Results and discussion

Diurnal variations of CO_2 profiles

Diurnal variations of CO_2 profiles during the full-leaf period in the forest were shown in Fig. 1.

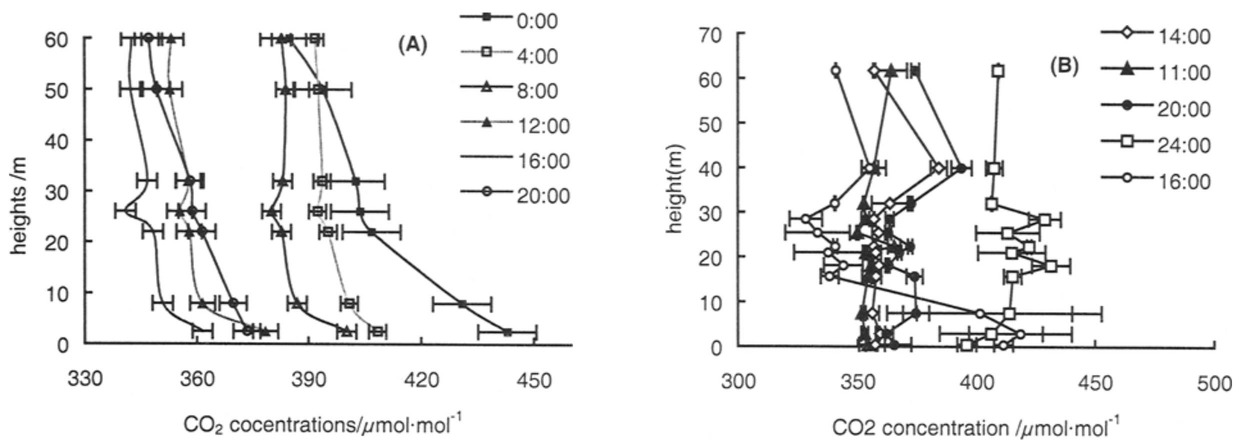

Fig. 1. The vertical distribution of CO_2 concentration in broadleaved / Korean pine forest of Changbai Mountain
(A) Data measured by LI-COR-6262 on July 22, 2003; (B) Data measured by ADC-2250D on August 28, 1999.

From Fig. 1 (A, B), it can be seen that the CO_2 profiles gained by the two instruments were similar, but they were different for daytime and nighttime. During daytime, the profiles had a similar trend. The concentration gradient was greatest at canopy, lowest (almost zero) above canopy, while from the canopy to ground it continually increased.

With contrast to the daytime, the CO_2 concentration in nighttime was higher around canopy and close to ground, stratified within the canopy. The peak CO_2 concentration usually occurs just before dawn when the inversion breaks and the normal daytime profile is reestablished (Woodwell *et al.* 1973). At midnight (24:00) the CO_2 concentration at height of 2.5 m was consistently higher than that at any other height levels, for example, it was 58 $\mu mol \cdot mol^{-1}$ higher than that at height of 60.0 m. At the same height (2.5 m) the CO_2 concentration at 24:00 hour was 80 $\mu mol \cdot mol^{-1}$ higher than that at 16:00. Diurnal variation of CO_2 concentrations mean that the canopy acted as a source of carbon dioxide at nighttime and as a sink at daytime.

During daylight hours, CO_2 concentration was lowest at the canopy and at the layer of 3-m above the canopy, and concentration gradients were formed in the air layer and within the canopy. This distribution of gradient implies that the large amount of photosynthetic leaves within the canopy acted as a sink for CO_2 to draw down concentrations within the canopy (Skelly *et al.*1996). The gradient distributions depended on physiological activities of trees and atmospheric stability. The study of Bazzaz *et al.* (1991) showed that under calm wind conditions it is expected that a CO_2 profile will develop in a closed canopy, and the greatest gradient during the summer is probably because of temperature-dependent rates of photosynthesis and the sheltering effect of leaves which reduces turbulent exchange with the air in the canopy by air flow and by convection.

Seasonal variations of CO_2 profiles

Figure 2 shows the seasonal variations of CO_2 profiles during the leaf expansion, full-leaf, defoliation and dormancy periods in the forest.

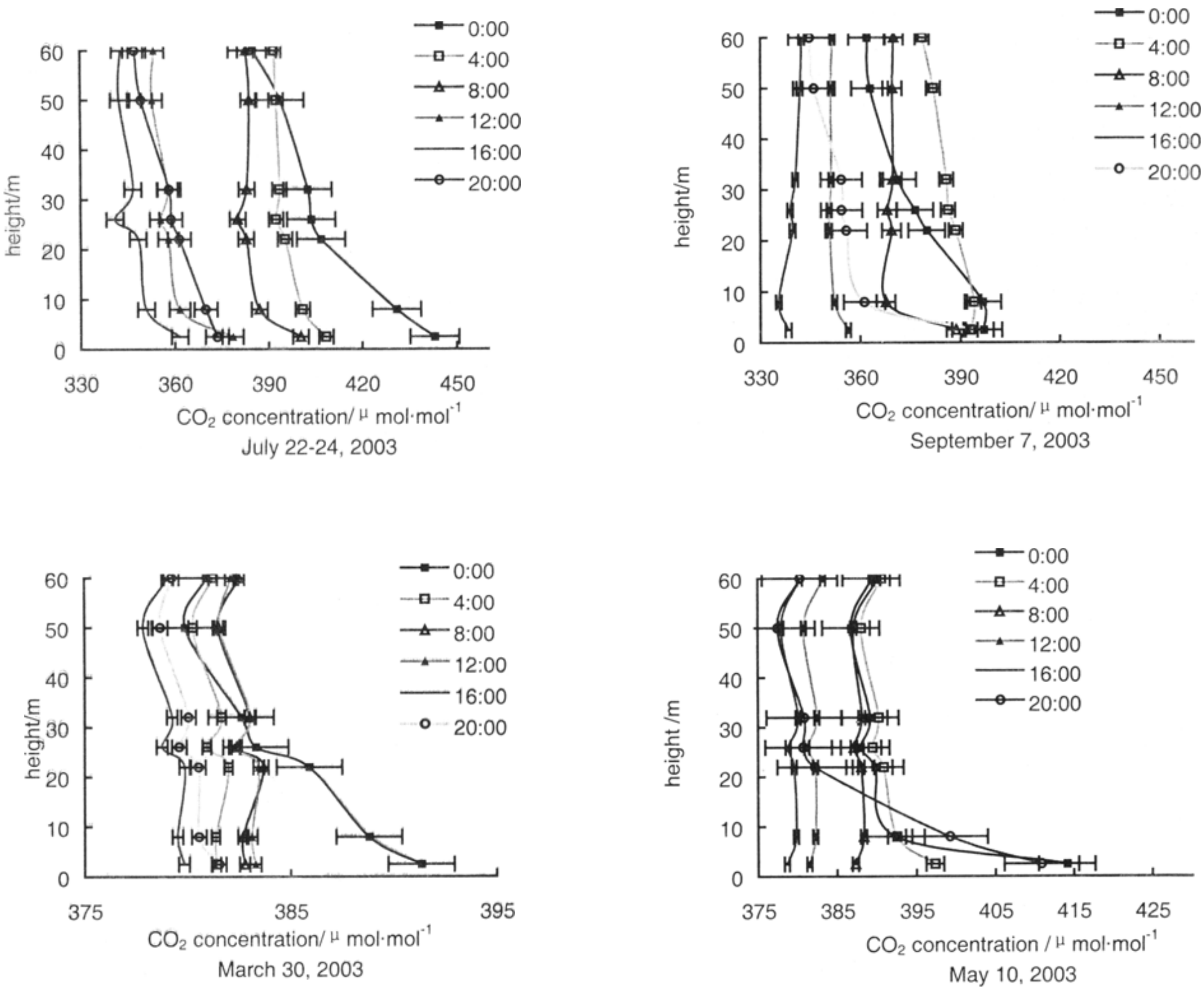

Fig. 2. The seasonal variation of vertical CO_2 concentrations in broadleaved/Korean pine forest in Changbai Mountain. (measured by LI-COR- 820)

From the seasonal profiles of CO_2 we can see that the trends of gradient variation at the canopy and near ground are significantly different. During dormancy season of plant, because the significant turbulent mixing could extend to understory due to the fact that there were very less leave left on the trees, CO_2 concentrations were nearly uniform

above and below the canopy, the gradient of CO_2 was the greatest near the ground, and the relations between the source and sink of carbon of the canopy was not evident. Here, as for the profile of the highest CO_2 concentration for diurnal variation, the difference in concentrations at heights from 60 m to 2.5 m was only as big as 10 $\mu mol \cdot mol^{-1}$. However, an evident seasonal pattern in CO_2 gradient will present as leaf development. Based on the analysis by Fig. 2, it is known that from May to September the leaves in the canopy plays an important role as the source or sink remarkably, and the concentration gradients in growth season at heights from 32 m to 2.5 m was greater than that in the dormancy period, which is probably resulted from radiative and evaporative cooling of the upper canopy (Wofsy *et al.* 1988).

During the full-leaf phase, CO_2 concentrations increased with descending of heights from 22 m to 0.4 m (see Fig. 1) and had rapid change at the time of sunrise and sunset. This result is consistent with Black's (1999). Such a gradient trend can help the understory layer utilize the carbon dioxide from the soil respiration and significantly increase assimilation (Sparling and Alt 1965) The difference between the highest and the lowest CO_2 concentrations at height of 2.5 m, was12 $\mu mol \cdot mol^{-1}$ in March, 36 $\mu mol \cdot mol^{-1}$ in May, 82 $\mu mol \cdot mol^{-1}$ in July, and 59 $\mu mol \cdot mol^{-1}$ in September. Similar trend was also present at height of 26 m (canopy). The greatest difference in CO_2 concentrations occurred in July. This means the photosynthetic function of canopy is most active in July. The differences of PAR measured at heights of 32.0 m and 2.0 m were 6.204 $\mu mol \cdot m^{-2}$ in July and 2.264 $\mu mol \cdot m^{-2}$ in September on monthly average. The differences of PAR had a same change law with that of CO_2 concentrations in respect to different growth periods.

From the gradient pattern of CO_2 (Fig. 3) we can see that stratification phenomenon in the canopy was more evident in the full-leaf season than that in non-growth season.

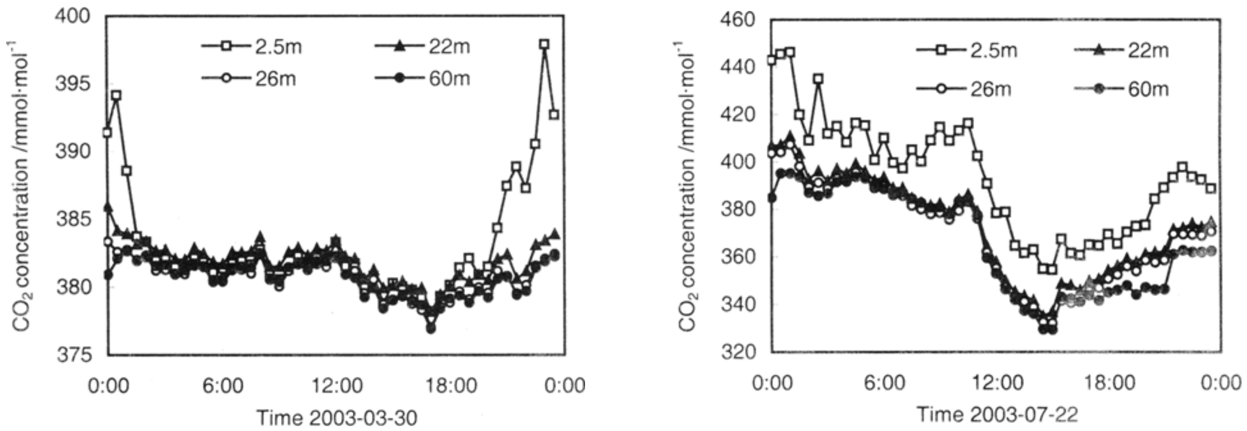

Fig. 3 Stratification of CO_2 in broadleaved/Korean pine in Changbai Mountain

Estimation of the CO_2 storage

Total storage ($\Delta C/\Delta t$) of CO_2 for the 0 to 40.0 m air column was negative, which indicated that the broadleaved/Korean pine forest of Changbai Mountain is a sink of carbon dioxide at present, and made a little contribution to NEE. The CO_2 storage measured in March, April, May, June, July, August, and September of 2003 was 0.56, 0.22, -1.66, –8.04, -3.56, -2.89, and -0.58 $mg \cdot s^{-1} \cdot m^{-2}$ respectively (Fig. 4). The monthly dynamics of CO_2 storage in plant growth season is closely related to stand characteristics and photosynthesis. Korean pine tree, which makes up 30% of broadleaved/Korean pine forest, have a higher photosynthetic rate in June, as a result, it needs a great amount of CO_2 to maintain its photosynthesis, thus bringing about lower CO_2 storage at the 0 to 40.0 m air column.

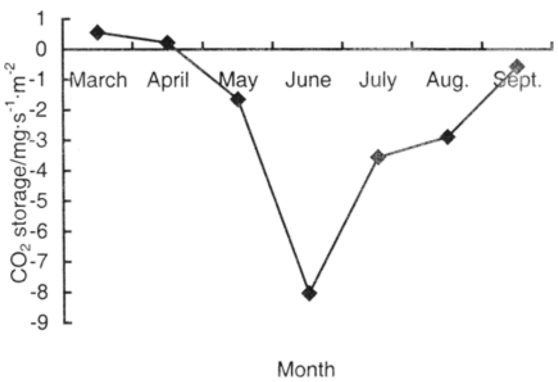

Fig. 4 The monthly dynamics of CO_2 storage in plant growth season in broadleaved/Korean pine forest of Changbai Mountain

Conclusions

Comparative analysis of diurnal and seasonal dynamics of the profiles and storages of CO_2 showed that: (1) The CO_2 profiles were different for daytime and nighttime in respect of diurnal change. In growing season, the drop of CO_2 concentration during daytime was most evident at canopy because of photosynthesis, and the canopy acted as a sink of carbon dioxide. During nighttime, the canopy acted as a source of carbon dioxide by respiration, and the stratification distribution of CO_2 was also evident. (2) The soil was a source of CO_2, and the CO_2 concentration was highest close to forest floor, no matter at daytime or nighttime and in growing or dormancy seasons. (3) The magnitudes of CO_2 gradient in the profiles at different season were accordant with seasonal law of tree growth. CO_2 concentrations at different heights (60 m to 2.5 m) had a little change in March, only with a difference of 10 $\mu mol \cdot mol^{-1}$, but had a significant change in July, with a difference of 60 $\mu mol \cdot mol^{-1}$. In July, there also existed a greater gradient of CO_2 concentrations at canopy (22, 26 and 32 m), with a difference of 8 $\mu mol \cdot mol^{-1}$. (4) Based on the collected dada, the diurnal and seasonal dynamics of profiles of carbon dioxide in broadleaved/Korean forest were analyzed. The calculated total storage ($\Delta C/\Delta t$) of CO_2 in the air column with height of 40 m beneath eddy covariance instrument was negative and made a little contribution to NEE.

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